Scaling in readout direction: a vibration-induced distortion of diffusion-weighted images and its retrospective correction by affine registration

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Introduction: Diffusion tensor imaging (DTI) offers the possibility of estimating quantities that are related to the brain's white matter (WM) microstructure, e.g. the fractional anisotropy (FA) [1].These quantities are frequently used for group comparisons (e.g. [2]). For DTI, at least seven images must be acquired [3]: one image with no diffusion sensitization (b0 image), and six diffusion-weighted (DW) images with diffusion sensitization in noncollinear directions. The large diffusion gradients lobes cause different kinds of MR artifacts like eddy current (EC) and vibration effects [4,5,6]. While EC effects could significantly be reduced by using a twice-refocused spin echo (TRSE) sequence for DTI acquisition [7], the vibration effects become more evident when the TRSE sequence is used [5]. Parts of the EC distortions can also be corrected retrospectively by registering the DW images on the non-diffusion-weighted image [4,8,9]. However, up to now no vibration-induced geometrical distortion of the DW images has been identified that could be retrospectively corrected. This study is a continuation of previous investigation of EC-induced whole-brain distortions, where the focus is now on vibration-induced distortions.

Objectives: (i) To show that the linear vibration-induced motion effects can lead to a whole-brain scaling of the DW images. (ii) To show that the *x* scaling that is determined by retrospective correction of MR artifacts is not related to EC effects and that it can be used to correct and assess vibration effects.

Methods: Two groups of, respectively 13 and 14 healthy right-handed subjects participated in this study. DTI data were acquired at 3T. The first group (DTI1) was investigated on a Gyronscan Intera (Philips, Best, The Netherlands) with a birdcage head coil and a pulsed gradient spin echo (PGSE) sequence (20 DW and 3 b0 images, NEX=2, matrix 128, 36 slices, thickness 3.6mm). The second group (DTI2) was investigated on a MAGNETOM TIM Trio (Siemens, Erlangen, Germany) with an 8-channel array and a TRSE sequence (60 DW and 7 b0 images, matrix 128, 72 slices, thickness 1.8mm). In analysis (i) we modeled the point-spread function (PSF) that is subject to a linear vibration-induced in-plane motion. We calculate the effective voxel size by the FWHM of the central lobe of the PSF [10]. In analysis (ii) we investigate the contribution of the *x* scaling and whole-brain EC parameters to the improvement of the tensor estimation, if two DTI data sets (DTI1 and DTI2) that differ in the EC and vibration effects are investigated. For this purpose, we used the relative error: $\partial\varepsilon(pi) = (\sigma_{11}(pi) - \sigma_{12})/\sigma_{12}$, where σ_{12} is the tensor error [8] calculated after correcting the MR artifacts by a 12-parameter-affine registration, and $\sigma_{11}(pi)$ is the tensor error after correcting the MR artifacts by a 11-parameter registration that is derived from the 12-parameter registration by fixing the parameter *pi* (see Fig. 2).

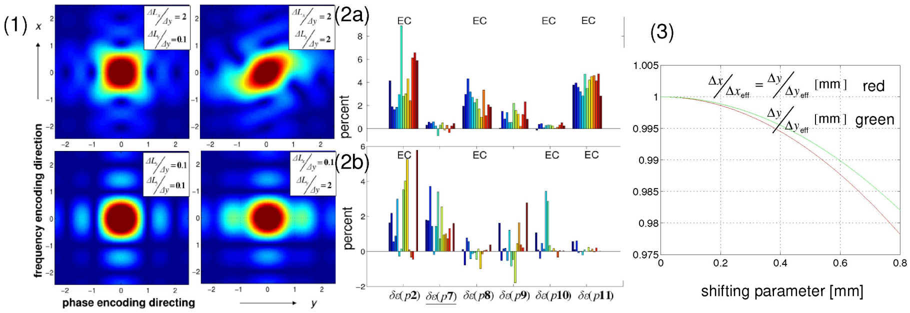

Fig. 1-3: (1) Absolute value of the 2-dim. PSF for different shifting parameters in *x* direction *ΔLx* and *y* direction *ΔLy* (PSF parameters: *N*=100; gridding: 0.05*;Δk=1/128*). (2) Relative error of the whole-brain EC parameters (y-translation: p2, y-scaling: p8, in-plane shearing: p10, and through-plane shearing: p11) and of the vibration-induced x-scaling (p7) for DTI1 (a) and DTI2 (b). (3) Modeled scaling parameter for two limiting cases: (a) for *ΔLx*=0 as a function of *ΔLy* (green); (b) for *ΔLy*=0 as a function of *ΔLx* (red).

Results and Discussion: (*i*) Linear motion in *x*-direction leads to broadening of the effective voxel size that is symmetric in *x* and *y*; whereas the linear motion in *y*-direction solely leads to broadening of the effective voxel size in *y* direction (Fig. 1). (*ii*) Taking the EC parameter into account leads to an improvement of the tensor error that is greater for the DTI1 data set relative to the DTI2 data set (Fig. 2). These results are in accordance with previous observations that the EC effects are smaller in the DTI data acquired by TRSE (DTI2) relative to PGSE (DTI1) [7]. Furthermore, we showed that taking the vibration parameter p7 into account leads to an improvement of the relative error that is greater for the data set DTI2 relative to DTI1. Again, these results are in accordance with previous observation showing that vibration effects are greater for DTI data acquired by TRSE relative to PGSE [5]. The scaling parameters s_x were between 0.995 and 0.997; this results in a linear shifting parameter between 0.2 and 0.7 mm (Fig. 3). This range agrees with experimentally determined shifting parameters [5].

Conclusion: We showed that the vibration-induced motion leads to an affine scaling effect in *x* and *y*-direction. While the scaling in *y*-direction is also subject to EC-induced distortions and thus cannot be correlated to vibration effects, the *x*-scaling seems to correct solely vibration-induced scaling effects. Thus, it might be a value that can be used for comparing vibration effects in different DTI data sets.

References: [1] Pierpaoli et al., MRM **36**, 893 ('96), [2] Deppe et al., Neurology **71**, 1981 ('09), [3] Basser et al., JMR B **103**, 247 ('94), [4] Haselgrove et al., MRM **36**, 960 ('96), [5] Hiltunen et al., NI **32**, 93 ('06), [6] Gallichan et al., HBM, *in press*, [7] Reese et al., MRM **49**, 177 ('03), [8] Andersson and Skare, NI **17**, 177 ('02), [9] Mohammadi ISMRM 17, 1405 ('09), [10] Liang and Lauterbur, IEEE Press, Inc. NY ('00).